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MONITORING OF STABILITY CONDITIONS AT FALCONBRIDGE'S STRATHCONA MINE

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July 1985

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37 pp

MINERAL AND ENERGY TECHNOLOGY
MINING RESEARCH LABORATORIES
DIVISION REPORT M&ET/MRL 85-93(TR)

MICROMEDIA
APR 23 1986

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ABSTRACT

Monitoring of stability conditions in underground mines permits management to assess the response of the rock mass to mining strategies. Monitoring of movements, if sufficiently early, may also permit operators either to avert potential failures or to develop alternative approaches to extraction.

The Falconbridge organization has been a leader both in the use of rock mass stability monitoring techniques and in the development of instrumentation.

In this paper, the authors review the Falconbridge approaches to monitoring, and present case history examples to illustrate the application of the various instruments used.

VÉRIFICATION DES CONDITIONS DE STABILITÉ DE LA MASSE ROCHEUSE À LA MINE STRATHCONA DE LA FALCONBRIDGE

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RÉSUMÉ

La surveillance des conditions de stabilité dans les mines souterraines permet aux chefs d'entreprises d'évaluer les réactions de la masse rocheuse aux méthodes d'extraction minière. Si le contrôle des mouvements du terrain est effectué assez tôt, l'exploitant pourra prendre les mesures qui s'imposent, soit pour éviter les détériorations possibles ou pour mettre au point de nouvelles méthodes d'extraction.

Le groupe de la Falconbridge a été le premier à utiliser des techniques de vérification des conditions de stabilité de la masse rocheuse et à mettre au point l'appareillage requis.

Ce document présente une revue des méthodes employées par la Falconbridge pour assurer la surveillance active de la stabilité de la masse rocheuse et illustre au moyen de cas concrets la manière d'utiliser les divers appareils.

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INTRODUCTION

Strathcona, the largest mine operated by Falconbridge Limited in the Sudbury District, is located on the northwestern rim of the basin - approximately 6 km (3 1/2 mi) northeast of the town of Levack, Ontario. Since large-scale production began in 1968 some 24,5 million tonnes (27 million tons) of nickel-copper ore have been hoisted from underground. Annual production, which attained a peak of 2 165 million tonnes (2 386 million tons) in 1971, was forecast at 1 566 million tonnes (1 726 million tons) for 1984. In terms of daily output these production figures correspond to rates of 9 070 and 6 530 tonnes (10 000 and 7 200 tons) per day, respectively. The mine operates for five days per week on a two-shift per day basis.

At the beginning of production, in 1968, Strathcona had been developed as a cut-and-fill operation with transverse stoping panels and rib pillars. In 1971, however, the rib pillars were converted to the "post" pillar cut-and-fill mining method (1). Subsequently, during 1972-1973, the method of breaking the ore was converted from uppers to flat-back open breasting onto tight fill. This method continues to be used.

In general, in most of the areas of the mine in which extraction is by cut-and-fill stoping, the stopes consist of a number of panels, generally 12.8 m (42 ft) wide, separated by lines of square "post" pillars. Pillars are commonly 6.1 m by 6.1 m (20 ft by 20 ft) and spaced on 15.24 m (50 ft) centres along pillar lines. In some areas of the mine there are variations from the typical dimensions given because of significant changes in the depths of stoping areas and local geology. On this latter point it should be mentioned that

there are great differences between the sizes, shapes and orientations of the Strathcona ore bodies.

The principal ore zones, of which there are three (Main, Deep, and Hanging Wall Zones), consist of lenticular sub-parallel lenses of nickel-copper-iron sulphides. The largest of these, the Main Zone, contains about 80% of the remaining ore. With dips varying from 60°S at the western end to 30°S at the eastern end, the zone may be visualized as a slightly twisted series of roughly parallel lenses. Occasionally, local variations may result in either flatter or steeper dips.

Within the main zone mineable widths, which are dictated by both geological contacts and grades, vary from about 3 m (10 ft) to over 91.5 m (300 ft). The zone extends approximately 915 m (3 000 ft) along an east-west strike, and from 470 m (1 600 ft) to 960 m (3 150 ft) below the ground surface. The levels at the mine are numbered according to the depths, in feet, beneath the surface.

It is noteworthy, and indicative of the lensoidal nature of the deposit, that no fewer than 36 sub-zones have been identified, for planning purposes, within the principal zones.

In 1978, only about 10% of the mine's production resulted from blasthole mining. Since then, however, the mine has been converted to what may be described as a combined cut-and-fill and blasthole operation. It was projected that about one-half of the 1985 production would be derived from blasthole panels.

At present, blasthole mining is used for both primary and secondary recovery of ore. With reference to the former, the method is used whenever the geometries of zones, and other circumstances, are favourable. With reference to secondary mining, the blasthole method is being used to recover rib pillars that were left in place, in the Deep Zone, prior to the conversion of "post" pillar mining, and the main sill pillar which divides the workings of the main zone horizontally at the 724 m (2 375 ft) level. The features of this latter application were described in a recent article (2).

In summary, the operations at Strathcona are now entering the period in which the secondary recovery of pillar ore will become increasingly important. Because mining in many areas of the mine will be in the latter stages, it can be anticipated that ground conditions will deteriorate.

BRIEF HISTORY OF STABILITY CONDITIONS AT STRATHCONA

To date, most of the production from Strathcona has originated from either cut-and-fill stopes or from primary blasthole panels. With this in mind, it is not surprising that there have been no instabilities that have had regional implications. Those that have occurred have been completely local in character, and have resulted either from adverse geological conditions or from the effects of high stress concentrations.

Local discontinuities in the rock mass which are unfavourable to stability, such as joints and slips, can be expected to occur regularly. As a general rule, however, any instabilities which result are usually limited to an individual mining panel or opening. Since the dimensions of potential failures are dictated by the orientations of the planes which define the wedges or slabs, individual assessments are made to determine the potential masses involved and the appropriate actions. As would be expected, there have been occasional instances when such analyses have been necessary.

The effects of stress concentrations have been experienced either as failures or overbreaking above stope backs, or as rockbursts or shock disturbances within the rock mass. Neither of these have occurred frequently in the past.

Since 1970, however, there have been a number of instances (perhaps 10-20) when arch-shaped failures have occurred above the backs of cut-and-fill stopes. The heights of these failures, above stoping panels which are typically 12.8 m (42 ft) wide, have usually been in the range of 3 to 4.6 m (10 to 15 ft). This is in good agreement with the results of finite element analyses, which have indicated that the greatest height attained by an arch-type failure at Strathcona should be equal to about one quarter of the span of the opening below.

In 1980, four failures of this type took place during the period between March and August. Because the number of instabilities was much larger than usual, a major rock mechanics study was conducted. As the result, it was concluded that prominent weaknesses and higher-than-usual stresses had caused a deterioration of stability conditions in certain parts of the mine.

The remedial actions proposed included not only revisions to mining and to ground support practices (3) but also the installation of instruments

for both short-term and long-term monitoring. To a very large extent, the present approach to the use of instrumentation was initiated by the 1980 study.

Shock disturbances and occasional small rockbursts took place at Strathcona between 1970 and 1984. Only rarely, however, was any damage or interference with normal mining activity associated with these. There is no evidence to suggest that the frequency of disturbances increased during that period. Indeed, it could be suggested that the improvements to practices which resulted from 1980 study caused a reduction in the types of conditions which result in bursting. To illustrate this point, it is now preferred that the first mining of a new cut, in a cut-and-fill stope, should take place along the weaker footwall contact area. This, together with the avoidance of conditions which may result in high stresses, has probably reduced the potential for bursting quite considerably.

During the period of 1974-1975 a large number of shock disturbances and rock bursts occurred, in a localized area between the 800 m (2625 ft) and 838 m (2750 ft) levels, as a major block of ore was being mined in the vicinity of an important transverse dyke. Most of the activity was reported to have taken place in the footwall rocks, and particularly in the vicinity of the ore transfer raises that are a feature of the Strathcona ore-handling system. Upon the conclusion of mining in this area, the frequency of rock noises in the mine was reduced considerably.

Most recently, however, the numbers of rock bursts and shock disturbances have increased quite considerably. The former can usually be attributed to some particular cause, such as the mining of a stope cut in proximity to a level. The latter are much more difficult to relate to particular causes and a clear pattern is not evident at present. It is expected though, that activity in the surrounding rock mass will increase as mining of the Strathcona deposit continues towards its conclusion.

GEOLOGICAL SETTING AND NEEDS FOR MONITORING

The nickel-copper-ore sulphide minerals occur, for the most part, in a Late Granite Breccia. The ore-bearing breccia is bounded by Norite, as the hanging wall, and a Felsitic Gneiss (Granite), as the footwall. Large dyke-like or still-like inclusions of Pyroxene Hornfels occur frequently both in the footwall and near the footwall contact.

Contacts between Pyroxene Hornfels inclusions and the ore breccias are typically very weak. Separations and failures along contacts are common and are the principal causes of difficulties in the mining of the footwall sections of stopes. Short-term monitoring of such areas is a common practice.

Structurally, the local rocks and ore-types may be described as being moderately to heavily jointed. There is much variability in the spacings of joints throughout the rock mass, however, with spacings ranging from centimeters to metres (inches to several feet). Orientations seem to be random except in the immediate areas near dykes and Pyroxene Hornfels inclusions.

Typically, the joints in the hanging wall rocks and in the ore zones tend to be both pervasive and slickensided. Those in the footwall have been altered to a much lesser extent. The effect of this on stability is that mining often results in the undercutting of wedges and slabs. Occasionally, under most unfavourable conditions, the dimensions may approach those of a stope panel. Instrumentation is used very often to monitor the stabilities of important blocks and wedges that have been identified in stope backs.

Diabase dykes of two types have been intruded into the local rocks. The older of these, Quartz Diabase, are coarse-grained and wide. In some areas of the mine rock bursting has occurred in the stronger diabases as the result of nearby mining. Very large slabs may result from failures.

Dykes of the younger, Olivene Diabase, on the other hand, are much narrower and finer-grained. Finely-spaced columnar jointing is a characteristic of this diabase - with the result that such dykes are very weak. A "coal-like" appearance is very common.

Locally, the presence of either type of dyke has implications as regards stability. As mentioned, the Quartz Diabase are known to accumulate strain energy and to burst. The Olivene Diabase, however, because of exceptional weakness, are often important elements in falls of ground. As will be discussed, the implications regarding monitoring are somewhat different.

All of the above structural features may result in situations for which monitoring is required. Short-term monitoring, using particular types of instruments, is often required when situations of only local importance have been defined by structural features - as in the opening of a stoping panel. Long-term monitoring, on the other hand, is most often applicable when the stability implications are of a regional importance.

After reading the next sections of this paper, it will be evident that all of the instruments which the authors have described could be used for either purpose. Knowing this, it must be observed that the classifications which have been suggested are not intended to be mutually exclusive. Rather, these are intended to relate to the most likely uses for each type of instrument.

INSTRUMENTS FOR SHORT-RANGE MONITORING

(i) Ground Movement Monitors (Gmm's)

The Ground Movement Monitor, developed at Falconbridge, consists of a linear variable resistor encased in a shell made from hexagonal aluminum stock (Fig. 1,2). The case is threaded at one end, for attachment to a standard rockbolt. A moveable centre-shaft, which passes through the potentiometer and which is attached to a mounting bracket, passes through the other end of the case. The device is currently available from Frema Research and Development Ltd., of Garson, Ontario.

Ground Movement Monitors permit one to detect any movements which take place between the anchors of the rockbolts to which these are attached and the mounting brackets (Fig. 3). With both ends being fixed, movement causes the core to be displaced in the potentiometer coil. The change to the electrical output which results may be related, through either calibration or stated factors, to movement.

In theory, Ground Movement Monitors can be developed to accommodate any size of linear potentiometer that is available. In practice, the instruments used at Falconbridge have an effective range of 10.16 cm (4 in.). This has been found to be more than adequate, as much lesser movements normally precede failures in the hard brittle rocks of the Sudbury region.

GMM's are usually installed for the purpose of detecting the rates, if any, at which separations take place between important fracture surfaces. The joints and slips which define potentially dangerous slabs and wedges are prime examples. Frequently, instruments are installed in the more heavily fractured rocks near the footwall contacts in cut-and-fill stopes. Areas which are used for travel, such as raise entries, are often monitored.

A recent situation, in which it was decided that several GMM's be installed, is illustrated in Fig. 4. In this instance, a number of important

fractures and slabs had been identified in the back as the stope cut had proceeded. The installation of monitors, and the obtaining of readings at regular intervals, enabled all concerned to establish that any movements that took place were within acceptable limits. The mining of the cut was concluded without incident.

At Strathcona, installations of GMM's may be requested verbally by miners, supervisors, or Ground Control personnel. A typical installation, including the drilling of a 3.66 m (12 ft), 3.18 cm (1 1/4 in.) diameter, hole requires about 1 hour. Removals of instruments, before blasting or filling, may be done very quickly. It is an important point that the use of these instruments is very well accepted by all concerned, and has minimal implications as regards disruptions to working routines and interference with production.

Previously, it was mentioned that it has been indicated through theoretical finite element studies that zones of potential failure above the backs of cut-and-fill stopes should be limited to heights equal to about one-quarter of the spans of the openings. With this in mind, it is anticipated that arched failures above the usual 12.8 m (42 ft) wide cut-and-fill stoping panels should extend for approximately 3 m (10 to 11 ft) into the backs. Observations, after the few failures that have taken place, have confirmed that these dimensions are substantially correct.

Because of this, it is standard practice that 3.66 m-long (12 ft) holes are drilled for Ground Movement Monitor installations. Shorter or longer holes may be specified to suit particular circumstances, but the latter may result in operational difficulties. In particular, because of the heights of openings, extension drill steel may be required.

(ii) Load Cells

Notwithstanding the usefulness of Ground Movement Monitors, there are many instances when other types of instruments are needed. Load cells, for example, are necessary if one wishes to measure the loads transmitted to supporting members, or if the deflections to be monitored result from deformations rather than displacements across fracture planes. At Strathcona, load cells are used principally to monitor the loads which may be developed on temporary support posts.

Typically, temporary posts are installed as a means of achieving short-term ground support when other alternatives are neither practical nor available. Load cells, installed on such posts in key locations, make it possible for one to determine the rate at which further deterioration in conditions, if any, takes place.

The load cells in use in the Falconbridge mines are rugged and inexpensive devices which were developed within the organization. In essence, the in-house designed cell consists of no more than a short-length of thick-walled steel pipe, to the inside of which a number of strain gauges have been bonded at equal intervals along the circumference, and connected in series-parallel (Fig. 5). The ends are capped with circular flat plates which are either welded or press-fitted to the pipe. In some older models the ends were bolted to each other, across the pipe.

Before being shipped to the various mines, the cells are calibrated. While sufficiently durable to withstand the handling and use resulting from a number of installations, it is not unusual for either re-habilitation or re-manufacturing to be required at some stage. One of the great advantages of the Falconbridge approach is that both the initial manufacture and any subsequent re-conditioning are comparatively inexpensive. Costs are much less than would be involved were commercially-available equipment to be used.

An interesting recent example, in which load cells were used for short-term monitoring, is illustrated in Fig. 6. In the case described, a new cut in a longitudinal cut-and-fill stope was being developed from the uppermost of the two ramps which provided access. Simultaneously, entry to the new cut, from the lower ramp, was also provided by travelling up beneath a brow between the cuts. At this particular stage in the mining of the stope, because of the grades of the ramps, the principal access was being converted from the lower ramp to the upper ramp. Consequently, future access to the stope from the lower ramp was to be provided by a travelway.

During the period before the timbered manway could be constructed and fill poured around it, timber posts were used to provide additional support to the hanging brow. Load cells installed on the posts were aids to determining the stability of the brow.

The results which were obtained are shown in Table 1. It should be noted that, even though increases were recorded as mining continued, as expected, these were well within acceptable limits. No deterioration of the

brow took place until the conclusion of the new cut - long after the timbered travelway through the fill had been completed.

Table 1 - Readings from load cells installed under a hanging brow in a cut-and-fill stope

Time (days)	Load cell 1 tonnes	(tons)	Load cell 2 tonnes	(tons)
0	4 .0	(4.4)*	3.08	(3.4)*
5	2.9	(3.2)	3.08	(3.4)
22	3.45	(3.8)	4.81	(5.3)
27	6.8	(7.5)	9.8	(10.8)
42	9.34	(10.3)	12.25	(13.5)

* initial load applied when load-cells installed

(iii) Rockbolt Load Cells

At the time of writing, a small number of rockbolt load cells were being evaluated on a trial basis. The cells, which were also developed within the Company, are shown in Fig. 7. As in the case of the post load cells the emphasis has been on the development of durable, low-cost, instrumentation.

At Strathcona, pull tests are performed on random samples of rockbolts in all of the working areas on a regular basis. Because these results are maintained in a log, and are therefore available for any analyses that may be required, there is no necessity of using rockbolt load cells for monitoring the tensions on bolts in the work places. To do so would involve much greater costs; not only for instrumentation, but also for the additional effort that would be required to both record and analyze data. The current thinking is that these cells should probably be used for special situations in which regular, high-precision, monitoring is needed.

An example in which these criteria are met is illustrated in Fig. 8. In this case, the elevation of a cut-and-fill stope was approaching that of the level above. Because the distances between the stope and the openings on the level were being reduced rapidly there was evidence of increased stresses in the area. These were in the form of spalling and increased noises in the local rock mass.

Normally, in cases such as this, the area would be de-stressed fairly promptly using specialized blasting techniques. De-stressing, however, is considered to be most effective when the stresses have been permitted to increase almost to the point at which natural stress relief (i.e., bursting) might take place. De-stressing at other times may be much less cost-effective.

With this in mind, rockbolt load cells were used as aids to the process of determining the time at which de-stressing would be attempted.

The results that were obtained for this trial are given in Table 2. It is interesting to note that the initial period, during which stresses increased, was followed by one of progressive, non-violent, natural stress relief. The fact that monitoring results were available, and that these indicated that conditions had not approached those at which de-stressing would be most effective, were key elements in the decision to defer, and ultimately forego, de-stress blasting. Monitoring, in the case, was responsible for saving the costs of drilling, blasting, and the subsequent clean-up. The latter can be considerable.

Table 2 - Readings from rockbolt load cells installed in a potential area for de-stressing

Time	Load cell 1		Load cell 2	
(days)	tonnes	tons	tonnes	(tons)
0	2.72	(3.0)*	2.72	(3.0)*
2	3.27	(3.6)	3.36	(3.7)
5	3.63	(4.0)	3.63	(4.0)
27	3.36	(3.7)	3.72	(4.1)
40	3.90	(4.3)	3.81	(4.2)
51	4.08	(4.5)	3.99	(4.4)
56	3.99	(4.4)	4.08	(4.5)
68	3.99	(4.4)	4.08	(4.5)
85	4.35	(4.8)	4.17	(4.6)
97	3.90	(4.3)	3.81	(4.2)
120	3.54	(3.9)	3.36	(3.7)
139	3.45	(3.8)	3.18	(3.5)
173	3.63	(4.0)	3.08	(3.4)
191	3.18	(3.5)	2.81	(3.1)
205	2.90	(3.2)	2.81	(3.1)
223	2.72	(3.0)	2.81	(3.1)

* initial loads applied during installation

(iv) Gloetzl Cells

Earth pressure cells have used for a considerable period in Civil Engineering practice. Typical applications include measurements and/or monitoring of pressures in embankments, beneath foundations, and behind retaining walls. In underground Mining Engineering practice the most important use is proba(-BEEP-) in connection with detecting the pressures in stopes filled with either classified mill tailings or alluvial sands.

In some of the Falconbridge Mines earth pressure cells, of the Gloetzl type, have been used during a comprehensive program of monitoring pressures at various points in filled blasthole stopes. The program, necessitated by recent changes to legislation, has been organized to provide data concerning

the pressures behind fill fences and above plugs of enriched cemented fill during all of the stages of the filling of high blasthole stope panels. Gloetzl, hydraulically-activated, cells have been found to be ideally-suited to the purpose.

The appearance of a cell and a schematic drawing to illustrate the way in which it functions are shown in Figs. 9 and 10, respectively. Referring to the latter, it should be observed that each fluid-filled cell is equipped with a diaphragm valve. When obtaining a reading the fluid, which is usually oil, is pumped into the system under increasing pressure until the valve opens at the point at which the internal pressure in the cell is equal to the pressure which is applied externally. At that point, the open valve causes the cell to function as a bypass in a hydraulic circuit. Further increases in pressure in the system, apart from temporary variations (of a minor nature) caused by pumping, are not possible.

From a mining point of view the major disadvantages of the cells are the weights of the larger models and the necessity of achieving hydraulic connections to a portable pump. The effects of both may be alleviated by careful planning of installation procedures. Cells are normally installed into position by being lowered from above once the hydraulic lines have been secured and any other necessary actions completed. The latter would include the final sealing of fill fences and the pouring of plugs of cemented fill in the former blasthole stope drawpoints.

A typical installation that was made during this monitoring program is illustrated in Fig. 11. In this instance, Gloetzl cells were lowered into position directly above the plugs of higher-strength cemented fill in the drawpoints. The pressures at these points were then recorded both during and after the filling process. Readings, in fact, continued for several months after the stoping panel was completely filled. The results form a most complete and valuable case history.

The results which were obtained are shown in Fig. 12. It will be noted that the pressures which resulted from filling were as would be expected. Increased rates of filling resulted in increased pressures, while decreased rates were followed by reductions. In view of the height of the panel, the pressures observed at all stages were very modest.

Of equal interest was the observation that pressures continued to decrease for many months afterwards as drainage, by then very slight, continued. Additionally, the pressures above one cell increased as the result of the mining of an adjacent panel. Similar, or greater, increases were expected to take place at the other cell as the result of future mining nearby.

Gloetzl cells are available with such a wide variety of optional features that the selection of a cell is a highly individualized matter. Those used in the project described were of the "E 40/40 K F 20 A" type, with the code meaning that the cells were:

"E" - protected with a corrosion-resistant paint (for burial in the acid environment of mine tailings backfill).

"40/40"- square cells, with a length of 40cm to the side (the largest cells available from the supplier).

"K" - intended to be filled with oil (for use in a low-modulus environment).

"F" - equipped with plastic membranes in the bypass valves (for use at pressures up to 50 bars).

"20" - designed for use at pressures not exceeding 20 bars (low-range, high-precision cells).

"A" - equipped with valves positioned at the centre of one side (chosen as being the most suitable configuration for the applications intended).

From the above, it can be appreciated that a very large number of combinations of possible design options is available. This is considered to be one of the greatest advantages of the Gloetzl system.

INSTRUMENTS FOR LONG-TERM MONITORING

All of the instruments which have been described thus far are used principally for short-term monitoring. In exceptional cases, however, provided that the durabilities of the instruments and the measuring capabilities are suitable, longer-range uses may be attempted. Normally, though, long-range monitoring implies that more elaborate and expensive equipment, applicable to a much broader scale of measurements, will be used.

(i) Extensometers

In underground mining applications, multiple point borehole extensometers are probably the most important instruments that are used for long-

range large-scale monitoring of the displacements around openings. The advantages are that, by installing anchors at several positions in a borehole, one is able to determine both the zone of influence around an opening and the rates at which changes take place. The major disadvantage is that installations, particularly in long boreholes, are very costly. To illustrate this, the total cost of a six-point extensometer with anchors equally-spaced in a 61 m (200 foot) long borehole may be as much as ten thousand dollars

At present, the choice of instrument may be made from a broad selection: connections between instrument heads and anchors may be with wires or rods, and the anchors may or may not be grouted in place. Read-out devices, and the instrument heads, may be based on either electrical or mechanical measurements.

At Strathcona, extensometers are used only when displacements on a regional scale are to be monitored. In most cases, it is possible displacements in the hanging wall above a mining zone which are of concern. Two recent examples, in which installations were made in the hanging walls above important mining blocks, are shown in Figs. 13 and 14.

In the first example (Fig. 13) a four-point extensometer was inserted, in an AX-size hole, in the blocky ground above a cut-and-fill stope. The intent was to follow the development of conditions in the back above the stope as mining approached the elevation at which a conversion to sill pillar recovery methods would be made. Following this conversion, which is now in progress, the behaviour of the hanging wall is being observed as the sill pillar is recovered.

In the second example (Fig. 14), two four-point extensometers were installed in the hanging wall above an area in which a sill is being recovered by blasthole stoping panels. The use of extensometers will permit an evaluation of the stability of the hanging wall as this takes place.

Some years ago, wire-type extensometers, with measurements being obtained mechanically, were used at Strathcona. In recent years, a conversion has been made to rod-type instruments with electrical readouts. Geokon Type A-3 multiple-position groutable rod-type extensometers, with either four or six anchors, are in use at present. A typical installation, and the readout unit, are shown in Figs. 15 and 16.

(ii) Sloughmeters

Sloughmeters were developed in the Company as a means of determining the rates at which sloughing might take place from the boundaries of openings which may be very dangerous to enter - such as ore passes and caving zones. Two of these devices are presently installed on the (2900 ft) 884 m level, near the location of the main dump into the ore pass. It is at such places that sloughing is most likely to occur.

In concept, the Sloughmeter is a very simple instrument (Fig. 17). It consists only of a length of multiple-strand electrical lead wire, with all of the strands connected to a common wire at regular intervals. When grouted into of a borehole, the device enables one, by testing the various circuits for continuity to determine if sloughing is taking place.

EXTENT OF INSTRUMENTATION AND USES FOR READINGS

Within the Falconbridge organization, at the operating level, the importance of instrumentation for stability monitoring is widely understood and accepted. This is because there have been several instances when the detections of movements have been sufficiently early to enable either the averting of a failure or the development of alternative mining strategies. Minor changes in plans, as the result of changes in stability which are indicated by instrument readings, are regular occurrences.

The instruments which are used for short-range monitoring in working places are readily available and are maintained as stock items in the mine warehouse. Installations may be requested verbally by miners, production or technical supervision, or Ground Control personnel. Since the Ground Control Technician usually carries a small number of Ground Movement Monitors whilst making routine visits to the stopes, these instruments in particular are often installed immediately. A minimization of bureaucratic procedures has been one of the key reasons for the high level of acceptance which is accorded to instrumentation.

Other important reasons include feedback and education. It is standard practice at Strathcona that all readings are either posted on a bulletin board in the Mine Captain's office or are maintained in logs in the Ground Control office. All data is available freely for review and discussion at any time.

Periodically, contributions are made either to technical meetings or to regular safety meetings of underground crews. At the latter, it is not unusual that the topic for discussion is chosen by the crew. Very often, the subject will involve the results obtained from monitoring in some particular area of the mine.

At such meetings, then, it is normal that a review is made not only of the current results and of the significance of these, but also of both the background and future plans. Particular attention is given to ensure that all are aware of the implications of any interpretations that have been made. Since monitoring is used as a tool to improve safety, much effort is given to making certain that it is understood.

The frequencies at which readings are obtained are dictated by both the general requirements for data and the particular circumstances. In long-range monitoring projects, in which extensometers are typically used, the normal practice is that data are obtained on a monthly basis. In short-range work, such as monitoring conditions in a stope back during the progress of a cut, or during filling, readings may be required on a weekly, daily, or shift, basis. In general, if movements occur rapidly or accelerate the frequencies of readings are increased.

SUMMARY AND CONCLUSIONS

All of the instruments that have been described in this paper have been adopted for general use within the Falconbridge organization. Some, notably extensometers and Gloetzl cells, have been chosen as being the most suitable from among the wide ranges which are presently available. Others, particularly Ground Movement Monitors and Sloughmeters have been developed in-house because of particular needs and the lack of available instruments.

With all underground monitoring instrumentation, the emphases must be on durability, reliability, and convenience. Equipment must be sensitive and yet sufficiently robust to withstand the abuses which result from use in an underground mining environment. Simplicity of design, ease of use, and an ability to make occasional simple repairs in-situ are absolutely essential.

The design of read-out units, in particular, require special mention. Read-out devices must be not only sufficiently sensitive to detect the small changes in strains which are a characteristic of hard-rock mining but also

easy to read and portable. Cumbersome, bulky, gear which is difficult to use is of little value in an active ground control program because people simply will not use it.

It is for this reason that much effort has been expended by Falconbridge on the development of ground monitoring instruments. At Strathcona Mine, where from 50 to 80 instruments are usually in place at any given time, the duties of obtaining readings are shared by production supervisors and Ground Control personnel. If there is to be an effective program on a mine-wide scale efficiency demands that appropriate devices must be developed if these are not available commercially at an affordable cost.

Within the field of instrumentation there are a great many opportunities for future developments. The use of micro-electronics should permit considerable reductions in the sizes of both read-outs and instruments. Likewise, using newly-developed technologies, there must always be better ways of approaching the subject.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to those of their predecessors at Falconbridge who have participated in the development of some of the monitoring instruments described, and to management for their permission to publish this paper.

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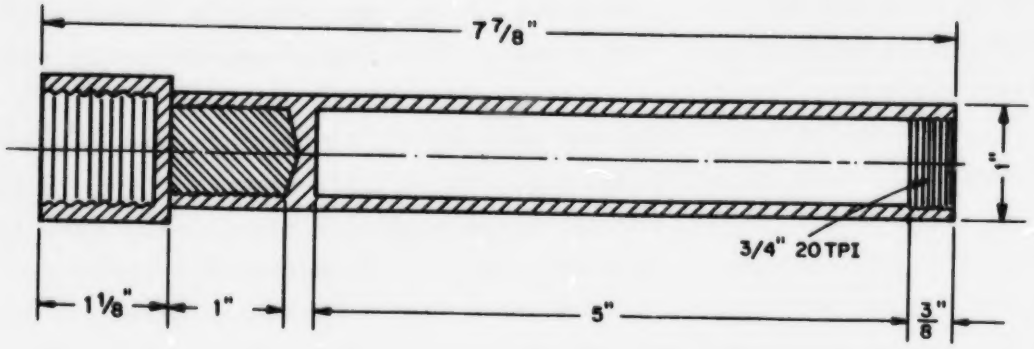
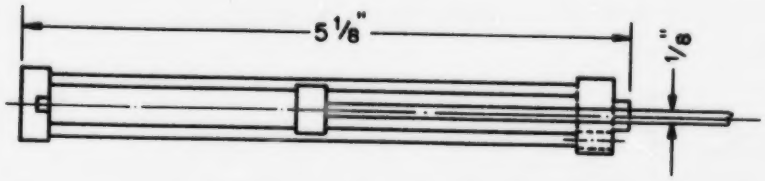
(2) Bharti, S., Lebl, J and Cornett, D.J., "Conversion from 'Post' pillar mining to blasthole - A case study at Falconbridge", CIM Bulletin, Vol. 76, No. 840, January, 1983.

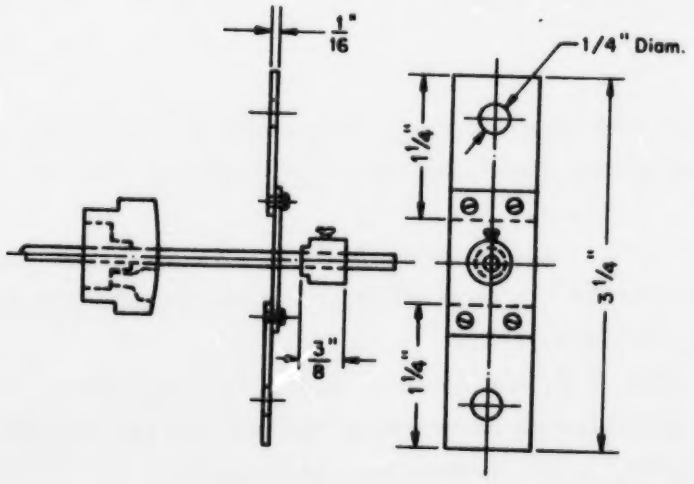
(3) Bharti, S., Udd, J.E. and Cornett, D.J., "Ground support of Strathcona Mine", CIM Symposium on Underground Support Systems, Sudbury, Ontario, September, 1983, 39 pp (proceedings in press).



Body – 1" Hex 2024 T4 Aluminum



Linear Resistor



Mounting Bracket Assembly
Aluminum

Fig. 1 - Details of the components of a ground movement monitor

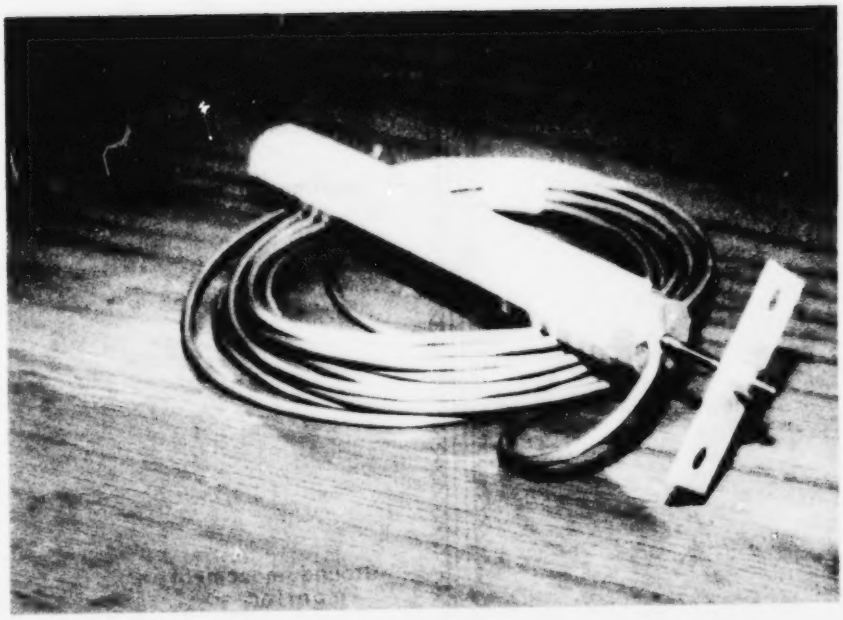


Fig. 2 - A ground movement monitor

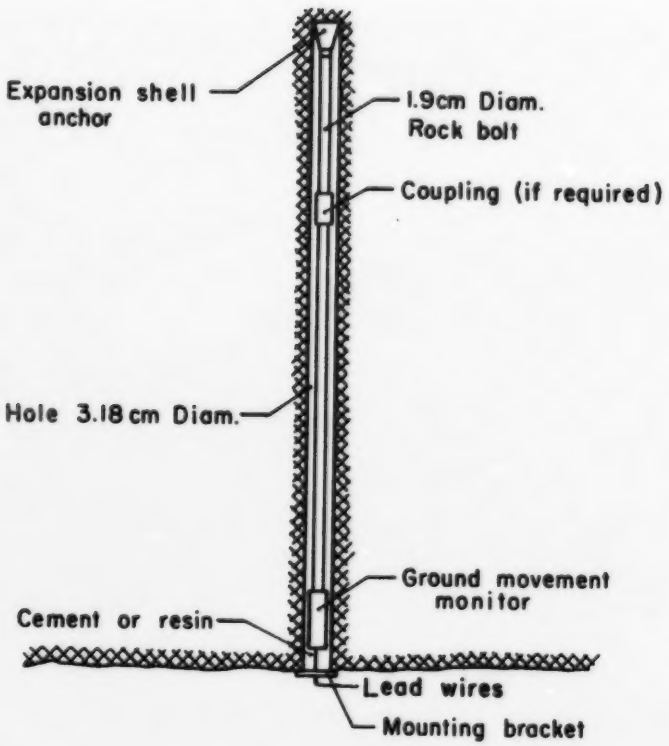


Fig. 3 - Sketch of a ground movement monitor installation

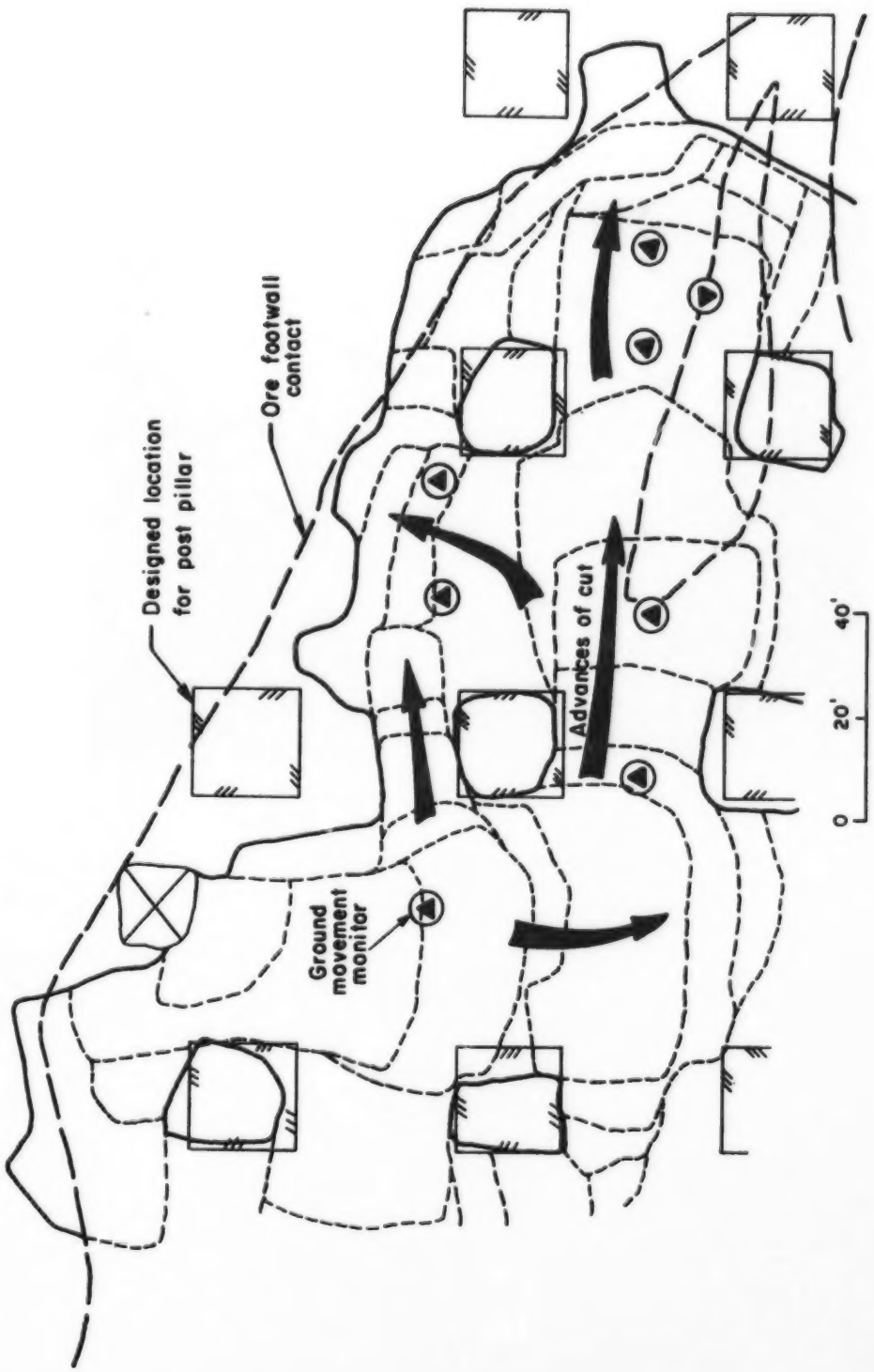


Fig. 4 - An example, in which several GMM's were installed as a cut in a cut-and-fill slope advanced

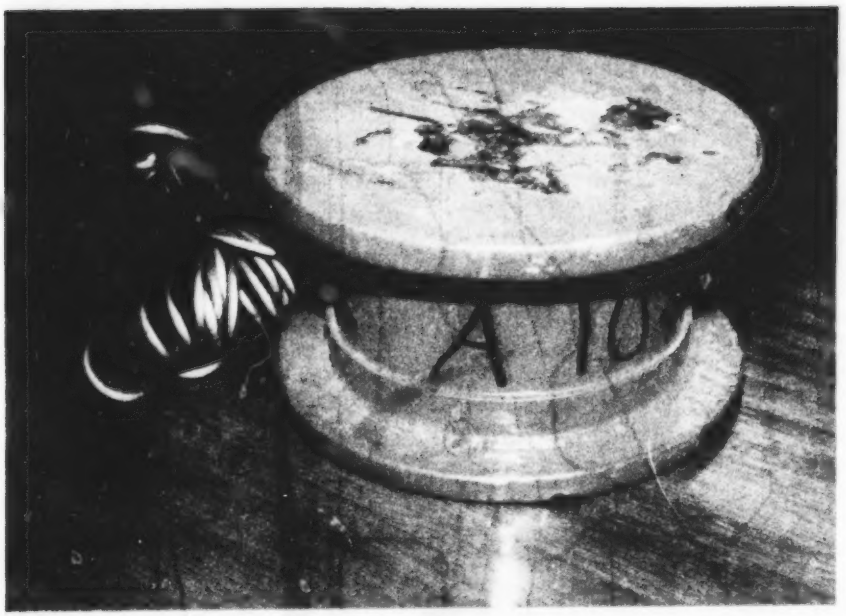


Fig. 5 - A load cell

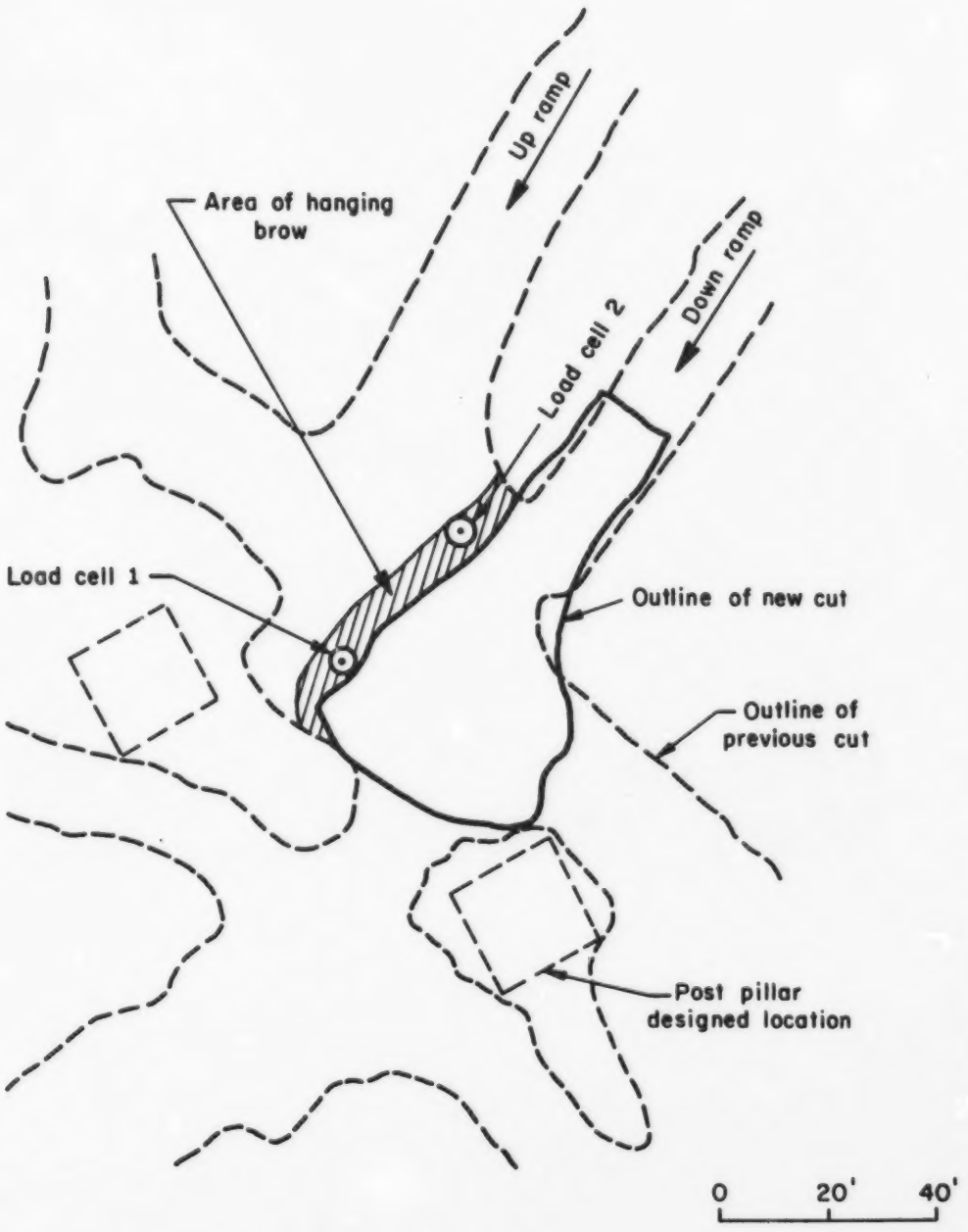


Fig. 6 - An example of a load cell installation

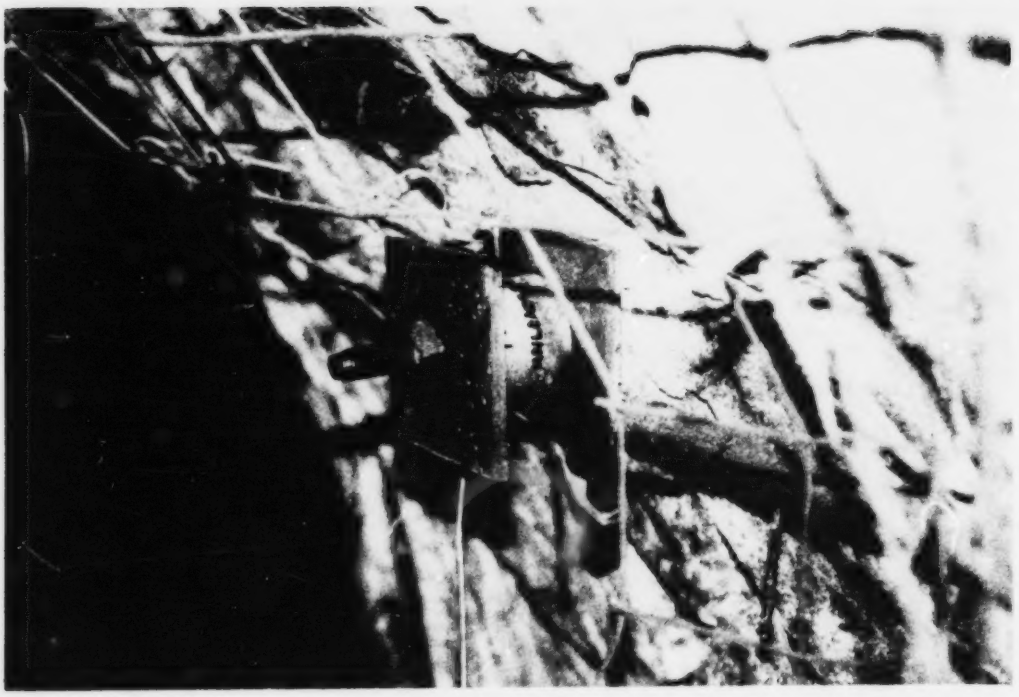


Fig. 7 - A rockbolt load cell

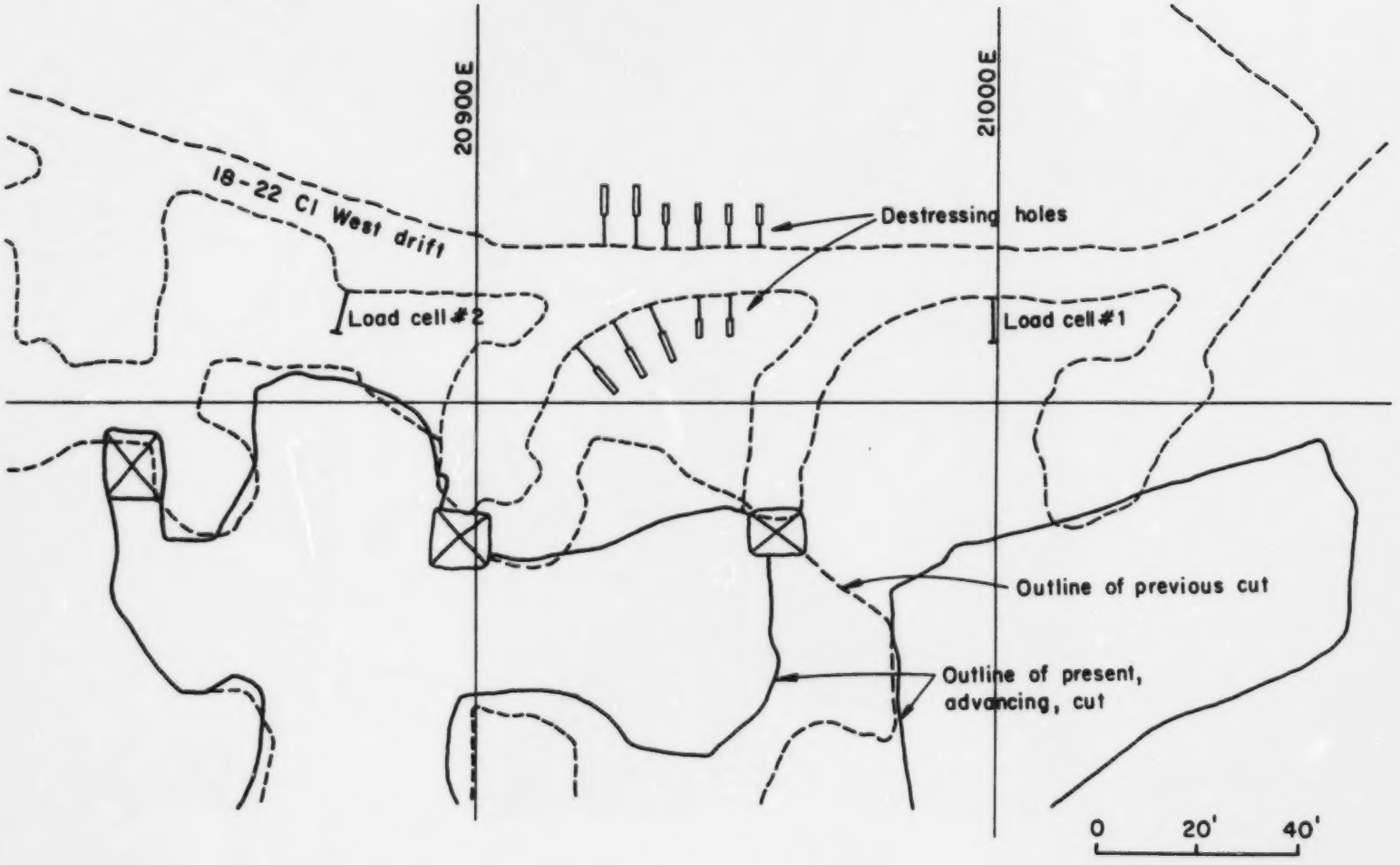


Fig. 8 - An example, showing installation of rockbolt load cells

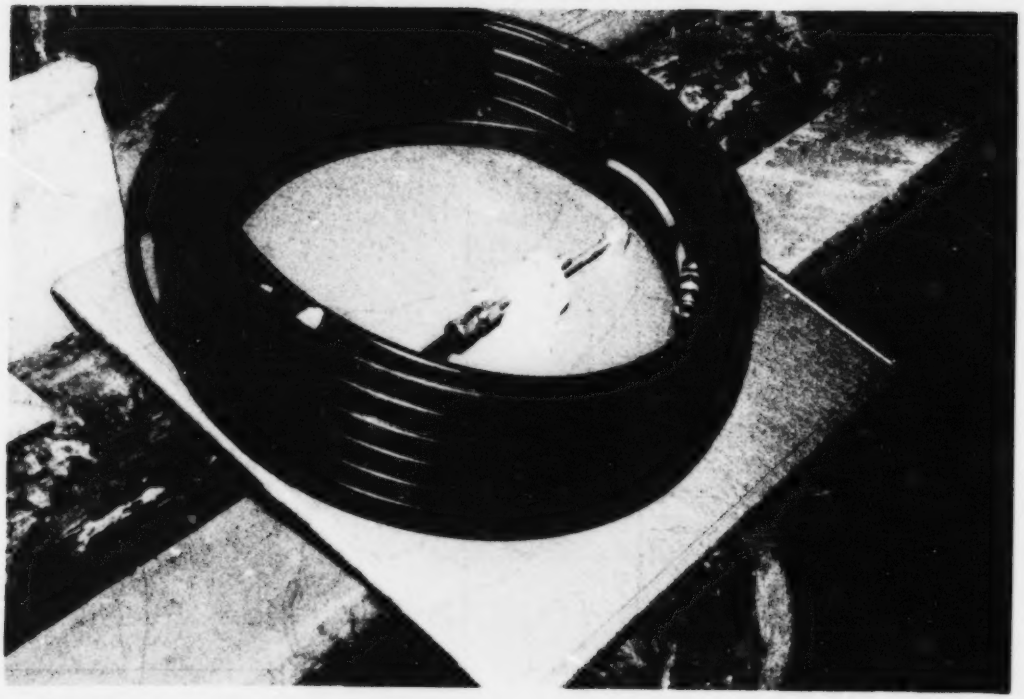


Fig. 9 - A Gloetzl cell

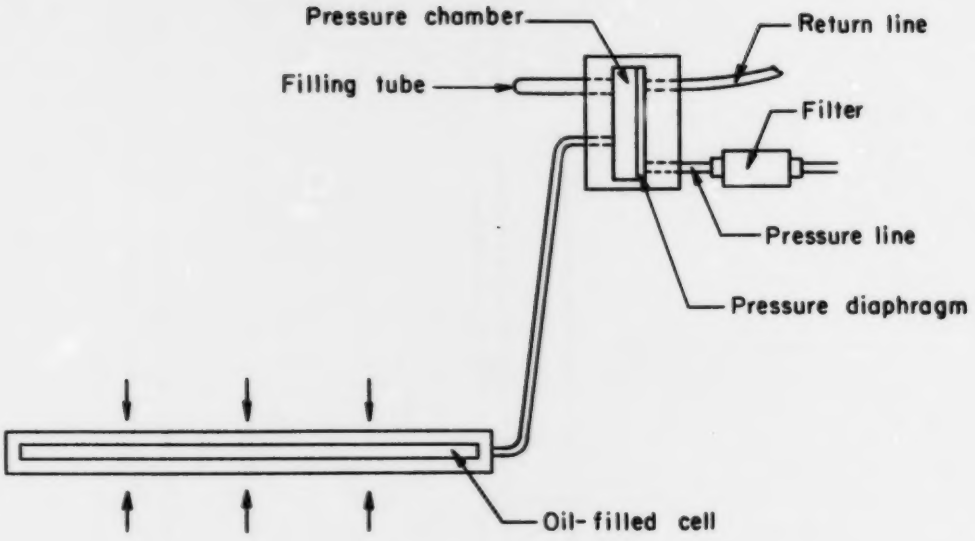


Fig. 10 - A schematic drawing of a Gloetzl cell

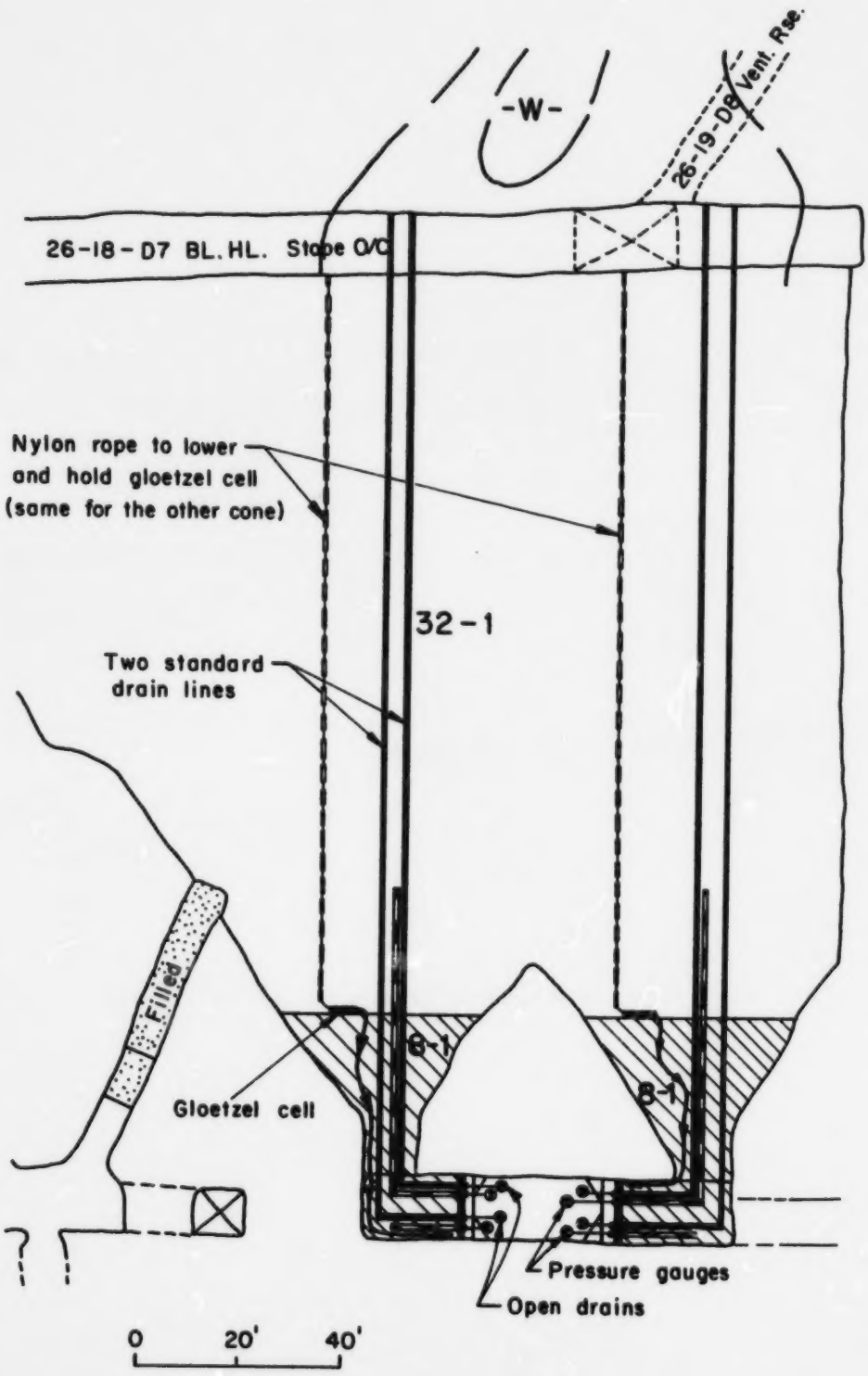


Fig. 11 - An example showing installations of Gloetzl cells

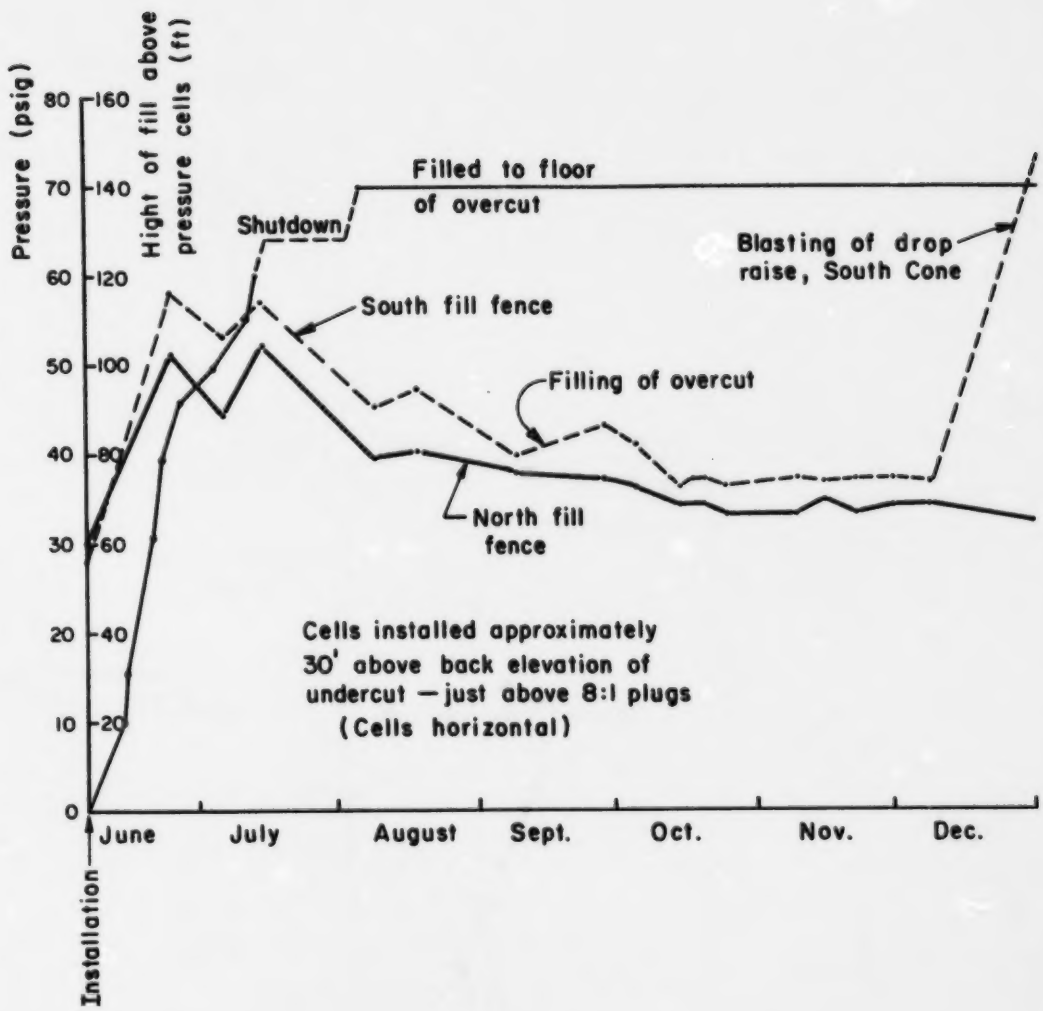


Fig. 12 - An example of the results obtained from monitoring pressures with Gloetzl cells

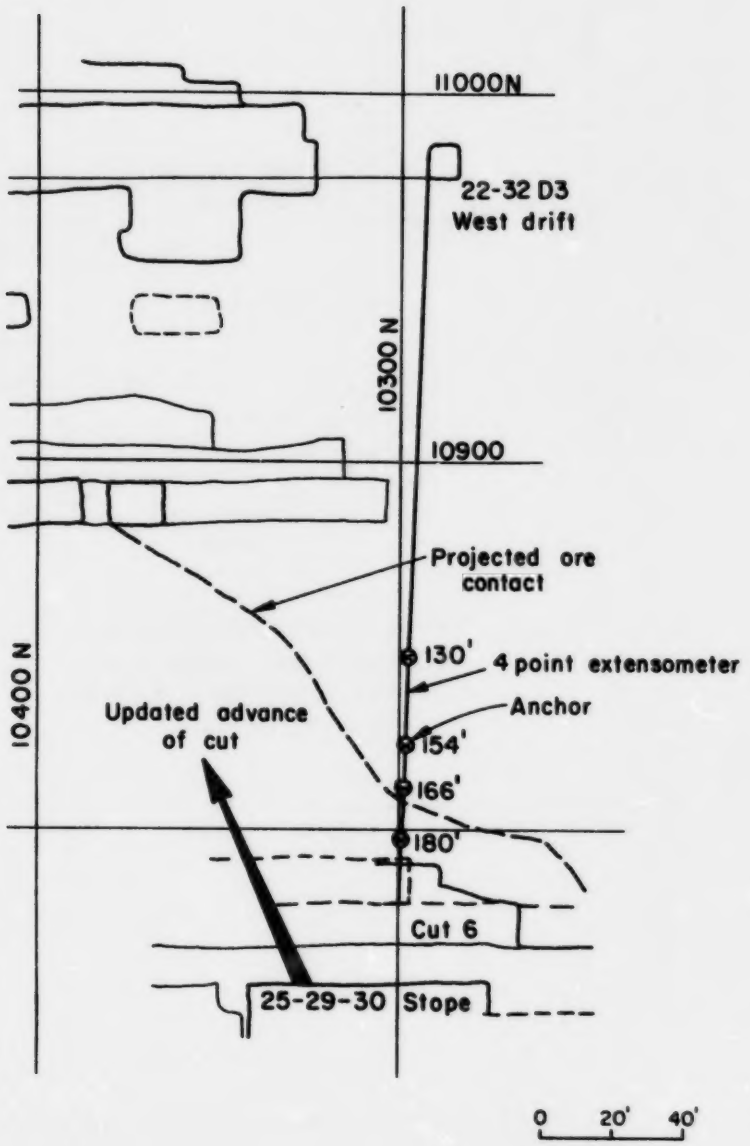


Fig. 13 - An example, showing the installation of an extensometer above a cut-and-fill stope

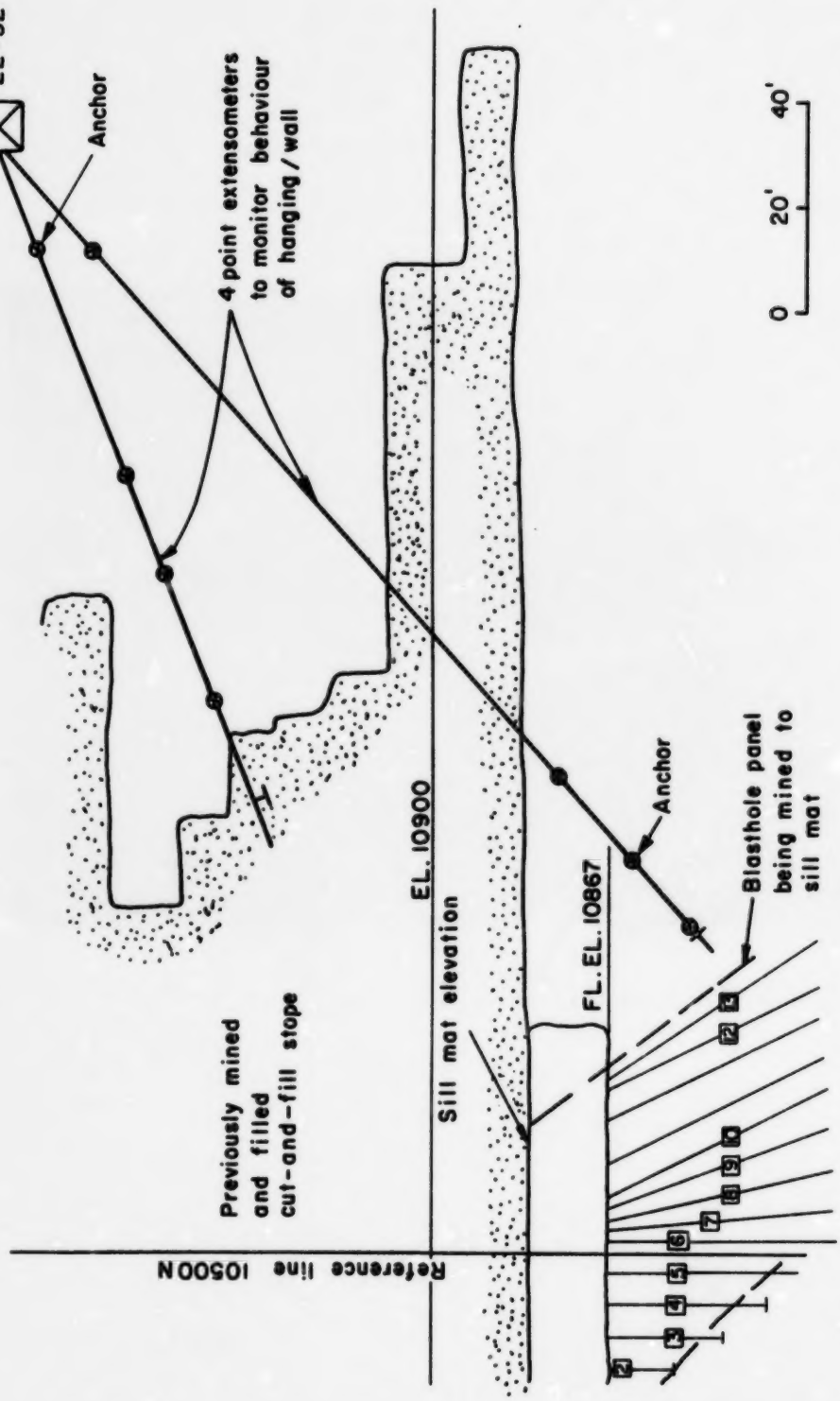


Fig. 14 - An example, showing the installation of extensometers above a sill pillar

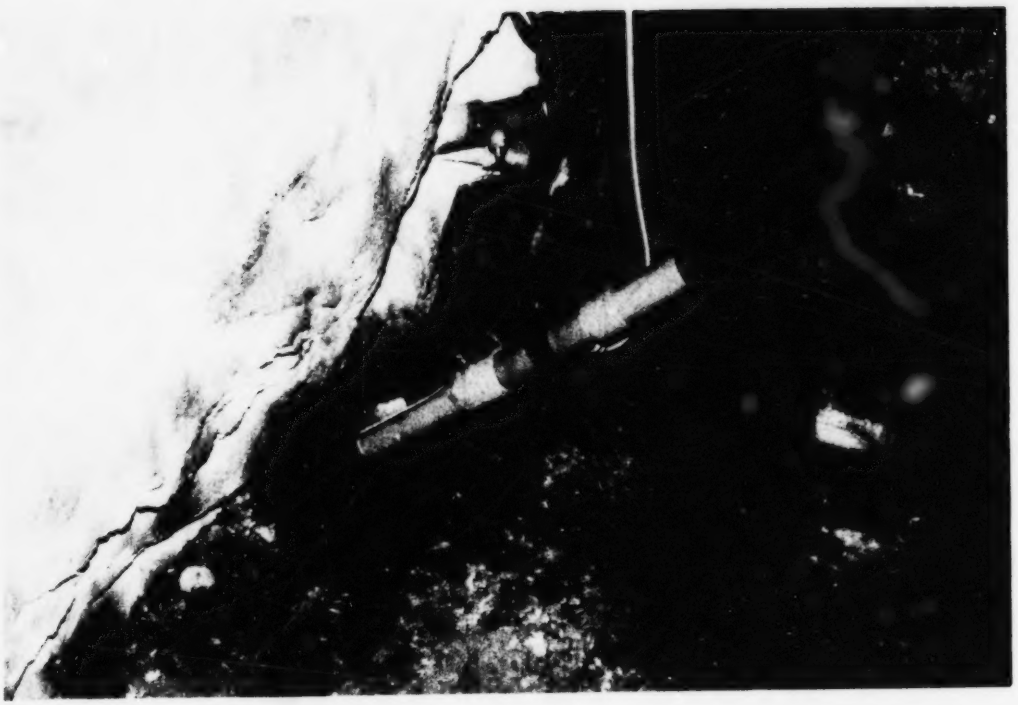


Fig. 15 - A typical extensometer installation

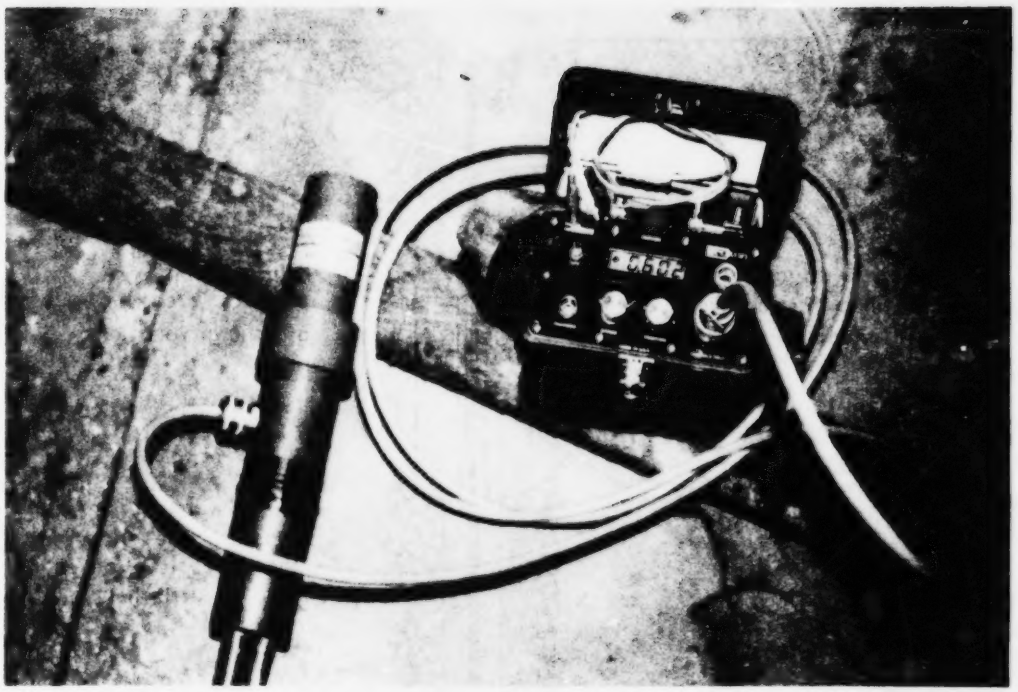


Fig. 16 - An extensometer readout unit

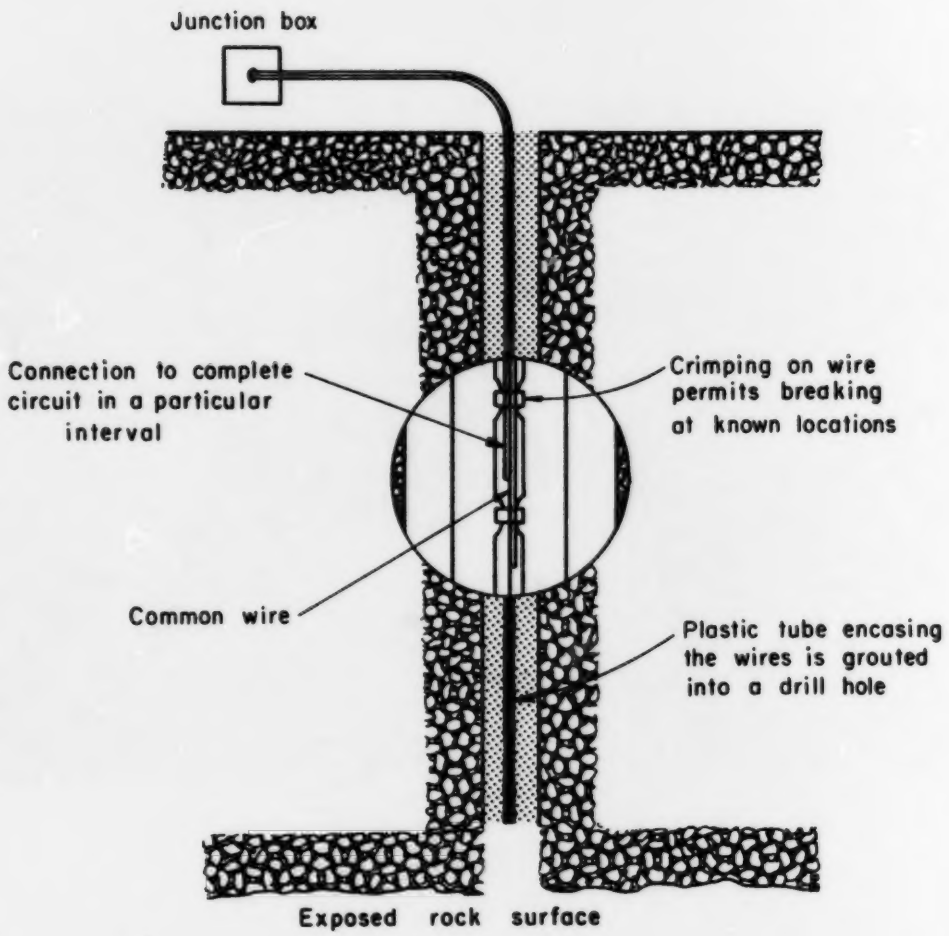

Junction box
Connection to complete circuit in a particular interval
Crimping on wire permits breaking at known locations
Common wire
Plastic tube encasing the wires is grouted into a drill hole
Exposed rock surface

Fig. 17 - Schematic drawing of a Sloughmeter, as installed